



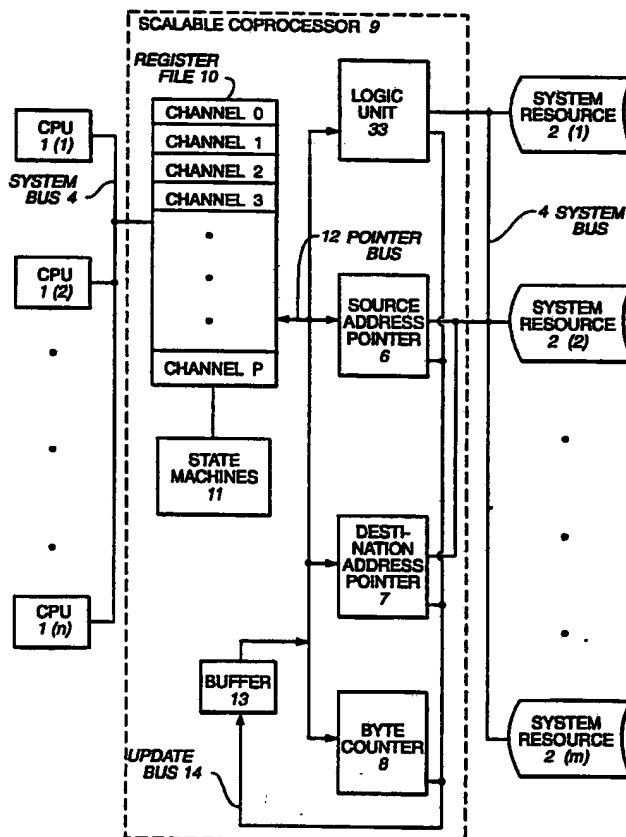
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification <sup>5</sup> : G06F 13/12, 13/28, 3/06</p>	<p>A1</p>	<p>(11) International Publication Number: <b>WO 93/23810</b> (43) International Publication Date: 25 November 1993 (25.11.93)</p>
<p>(21) International Application Number: PCT/JP93/00617 (22) International Filing Date: 11 May 1993 (11.05.93) (30) Priority data: 07/881,299 12 May 1992 (12.05.92) US (71) Applicant: SEIKO EPSON CORPORATION [JP/JP]; 4-1, Nishi-Shinjuku 2-chome, Shinjuku-ku, Tokyo 163 (JP). (72) Inventor: KANAGALA, Sameer ; 3500 Granada Avenue, #377, Santa Clara, CA 95051 (US). (74) Agents: SUZUKI, Kisaburo et al.; Seiko Epson Corporation, 4-1, Nishi-Shinjuku 2-chome, Shinjuku-ku, Tokyo 163 (JP).</p>		<p>(81) Designated States: JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  Published With international search report.</p>

(54) Title: SCALABLE COPROCESSOR

(57) Abstract

In a computing system, a scalable coprocessor (9) for enhancing communications between a set of central processing units (CPUs) (1) and a set of system resources (2). Scalable coprocessor (9) comprises a single register file (10) compartmentalized into at least two bins, each bin corresponding to a virtual coprocessor channel. Coupled to the register file (10) is a single actual coprocessor (6, 7, 8, 13, 33) for performing operations on the system resources (2). The number of virtual channels can be increased arbitrarily without the need to increase the number of actual channel hardware elements. A set of programmable state machines (11) grants operational authority to the virtual channels in the order desired and for the durations desired. Embodiments of the present invention include a fly-by DMA controller (23), an RAID coprocessor (29), and a striping coprocessor (23).



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1

## D E S C R I P T I O N

Title: SCALABLE COPROCESSOR

5 Technical Field

This invention pertains to the field of computing systems, and in particular to techniques for improving the communications between central processing units and system resources such as input/output controllers and memory.

10

Background Art

Figure 1 illustrates the conventional method by which central processing units (CPUs) communicate with system resources 2. The computer system comprises a set of m system resources 2, which can include memory and input/output controllers that are in turn coupled to input/output devices. The system comprises at least one CPU 1 for performing computational tasks, running stored programs, and communicating with system resources 2. Figure 1 illustrates a set of n CPUs 1, all of which are coupled to each other via a system bus 4, typically comprising a set of parallel data lines and a set of parallel address lines. System bus 4, for example, might have 32 parallel data lines and 32 parallel address lines. Using binary arithmetic, this is enough to address 4 Gigabytes of data at random. A bus master 34 is coupled to bus 4 and regulates access thereto.

A DMA controller 3 is associated with each system resource 2. All of the DMA controllers 3 are coupled to system

1 bus 4. On each DMA controller 3 is typically a bus arbiter 5,  
a source address pointer 6, a destination address pointer 7,  
and a byte counter 8. Bus arbiter 5 is a set of logic that is  
5 duplicated on all of the other DMA controllers 3. Bus arbiter  
5 stores priority information associated with that system  
resource 2 and indicates to bus master 34 that one of the CPUs  
1 wishes to activate the associated system resource 2. Bus  
master 34 then determines which of the DMA controllers 3 will  
be given authorization to become operational. Only one DMA  
10 controller 3 can be operational at any one time.

The way that a CPU 1 communicates with a system  
resource 2 is for CPU 1 to place, typically, three pieces of  
information into the associated DMA controller 3: the source  
address (the address where the data that are the subject of the  
15 communication are to be found) is stored in source address  
pointer 6; the address of the destination (location where the  
data are to be sent) is stored in address pointer 7; and the  
number of bytes desired to be moved is stored in byte counter  
8. During the operational period, byte counter 8 decrements  
20 once during each processing (clock) cycle until the count  
stored therewithin reaches zero, at which point it is known  
that all of the data have been moved. If CPU 1 wishes to  
perform operations such as arithmetic, logic, or shift  
operations on the data in addition to simply moving them, this  
25 task can be performed by CPU 1 during the operational cycle.

As will be seen, the present invention offers a much  
more efficient means for handling communications with the  
system resources 2.

1 "RAID Coprocessor", a data sheet by Extended Systems  
(date unknown), describes a device that, as does XOR pipeline  
30 of the present invention, frees a CPU from parity  
calculations in a RAID environment. However, this device can  
5 process only one block of data at a time, whereas the present  
invention can process multiple blocks of data simultaneously.

#### Disclosure of Invention

The present invention is a computer system comprising  
10 at least one central processing unit (CPU) (1) capable of  
performing operations on data stored within a set of system  
resources (2). A scalable coprocessor (9) is coupled to the  
CPUs (1) and the system resources (2) via a system bus (4).  
Within the scalable coprocessor (9) and coupled to the CPUs (1)  
15 is a single register file (10) that is compartmentalized into  
at least two bins, each bin corresponding to a virtual  
coprocessor channel. Coupled to the register file (10) is a  
single actual coprocessor (6, 7, 8, 13, 33) for performing  
operations on the system resources (2). Coupled to the  
20 register file (10) is a means (11) for apportioning the  
operational cycles of the actual coprocessor among the set of  
virtual coprocessor channels.

The present invention offers the following major  
advantages over the prior art:

- 25 1. The number of virtual channels can be increased  
(scaled) without the need to increase the number of actual  
channel hardware elements (such as items 5, 6, 7 and 8 of the  
prior art), since there is but one scalable coprocessor (9).

1           2. Fewer routing resources means consistent and  
high-speed routing across all virtual channels and higher  
system clock speeds.

5           3. More efficient use is made of the system bus (4),  
because the virtual channels operate in a time division  
multiplex mode, with fairness built in.

4. The means (11) for arbitrating which virtual  
channels gain operational access and for how long is  
programmable.

10          5. Dynamic updating of the pointer memory array  
(register file 10) by the host CPUs (1) without any unnecessary  
timing restrictions.

15          6. A more efficient way of performing scatter/gather  
operations (read and writes, respectively, when the data are  
fragmented among many blocks), because scatter/gather is  
performed in parallel rather than sequentially as has been  
conventional.

#### Brief Description of the Drawings

20          These and other more detailed and specific objects and  
features of the present invention are more fully disclosed in  
the following specification, reference being had to the  
accompanying drawings, in which:

25          Figure 1 is a block diagram of the conventional prior  
art technique of communicating among CPUs 1 and system  
resources 2;

        Figure 2 is a block diagram of scalable coprocessor 9  
of the present invention;

1           Figure 3 is a block diagram of state machines 11 of  
scalable coprocessor 9 of the present invention;

          Figure 4 is a sketch of amplitude versus time for gas  
pedal signal 15 of the present invention;

5           Figure 5 is a block diagram of a fly-by DMA controller  
23 embodiment of the present invention; and

          Figure 6 is a block diagram of a RAID coprocessor 29  
embodiment of the present invention.

#### 10   Best Mode for Carrying Out The Invention

          Figure 2 is a block diagram of a general embodiment of  
scalable coprocessor 9 of the present invention. The  
environment is a computer system which comprises at least one  
central processing unit (CPU) 1. Each CPU 1 can be any active  
15 processing element capable of performing an operation on a set  
of system resources 2. n CPUs 1 are illustrated in Figure 2.  
CPUs 1 are all coupled together via the same system bus 4. For  
example, system bus 4 may have 32 parallel data lines and 32  
parallel address lines. This is enough to address four  
20 Gigabytes of data at random.

          By using this invention, each CPU 1 can submit  
multiple I/O requests simultaneously. For example, a CPU 1 can  
be a file server that asks for hundreds of files simultaneously.

          System resources 2 are likewise coupled together via  
25 the same system bus 4. Only one operation can be performed on  
system bus 4 at any given time. System resources 2 comprise,  
typically, memory and input/output controllers that are in turn

1 coupled to input/output devices such as disk drives, tape  
drives, CD ROMs, Bernoulli boxes, etc.

There is needed only one scalable coprocessor 9 in the  
computer system. This eliminates the duplication of devices  
5 and data paths that was common in the prior art, such as that  
illustrated in Figure 1. Coprocessor 9 communicates with  
system resources 2 at speeds approaching memory bandwidth,  
e.g., 66 MBps in embodiments that have been built, rather than  
at slower CPU 1 bandwidths.

10 Scalable coprocessor 9 is coupled to CPUs 1 via system  
bus 4 and comprises register file 10, a set of state machines  
11, and an actual coprocessor comprising at least one address  
pointer (e.g., source address pointer 6 and destination address  
pointer 7), byte counter 8, buffer 13, and (optionally) logic  
15 unit 33. Pointers 6 and 7 are storage devices such as  
registers or programmable counters.

Register file 10 is a storage device such as a random  
access memory (RAM) that has been preselectedly  
compartmentalized into an arbitrary number of  $p+1$  storage areas  
20 or bins corresponding to the number of virtual coprocessor  
channels that the user of coprocessor 9 has decided to set up  
in advance. For example,  $p+1$  may correspond to the number of  
blocks of data that are known to be present in the computer  
system. Each bin or channel stores at least three pieces of  
25 information: the beginning address of the data that are to be  
used as the source for an operation, the beginning address of  
the desired destination for the data after the operation has  
been performed, and the size of the data that are the subject



1 of the operation. Additionally, information can be stored in  
the channel indicating the type of arithmetic, logic, or shift  
operation desired to be performed on the data.

5 The set of state machines 11 determines which channels  
are allowed to become operational in which order and for how  
long, based upon a programmable arbitration scheme stored  
within state machines 11. When a given channel is allowed to  
become operational, the stored source address from that channel  
is placed into source address pointer 6 via pointer bus 12, the  
10 destination address is placed into destination address pointer  
7 via pointer bus 12, and the byte count is placed into byte  
counter 8 via pointer bus 12. Additionally, the stored  
arithmetic, logic, or shift instructions, if any, are placed  
into optional logic unit 33 over pointer bus 12.

15 As coprocessor 9 is clocked through its normal  
operational cycles by a conventional clock (not shown), e.g.,  
at the rate of 66 Megahertz, the desired operations are  
performed. The source data are addressed by means of source  
address pointer 6 placing the source address over system bus  
20 4. The destination address is similarly accessed by pointer 7,  
again using system bus 4. If it is desired to perform an  
arithmetic, logic, or shift operation on the data and not just  
simply move them, logic unit 33 is invoked. Finally, byte  
counter 8 is decremented once per cycle.

25 Typically, state machines 11 allow each channel to  
perform a finite number of operations (corresponding to a given  
finite number of clock cycles) per operational authorization.  
128 cycles is a typical number. This may or may not be enough

1 cycles to permit the channel to complete its assigned tasks.  
If it is enough, byte counter 8 decrements to 0 and state  
machines 11 pass control to the next channel. If it is not a  
sufficient number of cycles, the status of items 6, 7, 8, and  
5 33 are passed over update bus 14 via buffer 13 and back to  
register file 10 over pointer bus 12, so that the next time the  
particular channel is granted operational authorization, it can  
resume where it was interrupted. Buffer 13 is needed because  
one of the CPUs 1 may be trying to initialize another channel  
10 within register file 10 at the same time that the updated  
information is being sent back to register file 10 over update  
bus 14. Thus, buffer 13 prevents collisions of inbound and  
outbound information.

Figure 3 illustrates in more detail the set of state  
15 machines 11. The first state machine is a programmable arbiter  
20, which may comprise random access memory plus associated  
logic devices. Arbiter 20 stores the programmable scheme for  
arbitrating which channels are given operational access and for  
how long. The programming scheme may entail the use of gate  
20 arrays, EEPROMs, fuses/anti-fuses, etc. The arbitration scheme  
may be any one of a number of techniques such as round robin  
(cycling through the channels in order and then repeating at  
the zeroeth channel), priority (giving authorization only to  
channels which are flagged with certain priority bytes or  
25 giving flagged channels a greater number of operational cycles  
than channels not flagged), etc.

A set of channel lines CH is input into programmable  
arbiter 20. These lines can originate from register file 10

1 (as illustrated) or from system resources 2. The purpose of  
these lines is to indicate whether the associated channels are  
active (desirous of performing operations on system resources  
2) or not. The output of arbiter 20 is a line conveying the  
5 number of the channel which is being granted operational access  
at any given time. This signal is fed to channel initialize  
and update module 21. One of the outputs of module 21 is a  
register file address index, which informs register file 10  
which channel is being given operational authorization. The  
10 length of this index is variable, depending upon the number of  
channels. For example, if there are eight channels, this index  
requires three bits.

The other output of module 21 is a channel ready  
signal. This signal is fed to gas pedal module 22. The  
15 composite output of gas pedal 22 is a square wave 15, whose  
amplitude versus time is illustrated in Figure 4. When gas  
pedal signal 15 is high, this indicates the presence of a  
throttle (operational) period 18, i.e., one in which operations  
on the data are being performed by actual coprocessor 6, 7, 8,  
20 33. When gas pedal signal 15 is low, this indicates the  
presence of an idle period 19 during which no virtual channel  
is allowed to be operational, but rather CPUs 1 rather than  
coprocessor 9 are given access to system bus 4. The durations  
of the throttle and idle periods 18, 19 are variable and  
25 programmable in advance.

The transition between an idle period 19 and a  
throttle period 18 is denominated as a wakeup signal 16 and is  
passed to arbiter 20, which induces arbiter 20 to perform a new

1 designation of authorized channel. The transition from a  
throttle period 18 to an idle period 19 is denominated as a  
tired signal 17, and is passed to arbiter 20 (commanding it to  
designate no channel as the designated channel). Tired signal  
5 17 is also passed to channel initialize and update module 21,  
inducing module 21 to instruct items 33, 6, 7, and 8 to send  
their status back to register file 10. This information  
becomes the beginning status for the next throttle period 18  
the next time that particular channel is given operational  
10 authorization by state machines 11.

Figure 5 illustrates a specific embodiment of the  
present invention: a fly-by DMA controller 23. This  
embodiment of scalable coprocessor 9 is used in conjunction  
with non-addressable devices such as input/output controllers  
15 25. Since these devices are non-addressable, one of the  
pointers 6, 7, from the general embodiment can be eliminated.  
Thus, a single input/output address pointer 24 is used to  
indicate where in memory 26 data to be read from or written to  
I/O controller 25 are stored. Pointer 24 points to the  
20 beginning location in memory 26 where the data are to be read  
from or written to. A separate request line 28 and acknowledge  
line 27 connects pointer 24 with each I/O controller 25. A  
signal is sent by I/O controller 25 over request line 28 to  
address pointer 24, asking DMA controller 23 to start each byte  
25 transfer. Similarly, a signal is sent from pointer 24 over  
acknowledge line 27 to I/O controller 25 for each byte that is  
transferred, signaling that system bus 4 is available to  
perform the read or write operation. Byte counter 8 decrements

1 for each transferred byte. This process continues until the  
byte count for the virtual channel becomes zero, at which time  
an interrupt is issued to the associated CPU 1 if required.  
The data move directly from memory 26 to the I/O controller 25  
5 over system bus 4, without going through controller 23. This  
is characteristic of a fly-by DMA controller, as opposed to a  
flow-through DMA controller.

A second embodiment of the present invention is  
illustrated in Figure 6: a RAID (redundant array of  
10 inexpensive disks) coprocessor 29. In this application there  
are  $m-1$  equally sized blocks of memory 26, where  $m-1$  is at  
least 2. The output is a set of  $m$  equally sized blocks of data  
that are written to a set of disk controllers 2. The  $m$ th block  
is a byte-by-byte parity check on the first  $m-1$  blocks. This  
15 permits fault tolerant processing: if any one block fails,  
including the parity block, all of the data can be  
reconstructed from the remaining blocks.

In this embodiment, register file 10 contains but a  
single destination pointer, because the writing onto the  $m$  disk  
20 controllers 2 is automatically partitioned equally among the  $m$   
controllers 2. Exclusive OR (XOR) pipeline 30 is a special  
case of logic unit 33. Every time a source block of data is  
read in from a memory 26, an exclusive OR (XOR) is performed  
byte by byte, e.g., 8 bits by 8 bits even when the words are 32  
25 bits long. After all of the  $m-1$  blocks of data have been read  
in, XOR pipeline 30 contains the parity block. This is written  
to the destination controller 2( $m$ ) along with the other  $m-1$   
blocks of data, which are written to the first  $m-1$  controllers

1 2. Pipeline 30 communicates with the memories 26 and disk  
controllers 2 over the data lines subset 31 of system bus 4.  
Similarly, address pointer 24 communicates with memories 26 and  
5 disk controllers 2 over the address lines subset 32 of system  
bus 4. The byte count stored in register file 10 is the same  
for each source 26, because each block of input data has the  
same number of bytes. State machines 11 give operational  
authority to the m-1 sources 26 sequentially.

A third embodiment of the present invention is a  
10 striping coprocessor. In a hardware sense, it is the same chip  
as the fly-by DMA controller 23, illustrated in Figure 5. The  
striping coprocessor 23 takes as inputs the m blocks of data  
that have been written onto the disk controllers 2 by the RAID  
coprocessor 29 and notionally (via software) stripes these  
15 blocks of data onto m I/O controllers 25. Striping is an  
intentional scatter, i.e., the data are fragmented into m  
equally sized blocks. The number of stripes and their widths  
are based upon hardware considerations.

Devices illustrated in Figures 5 and 6 have been built  
20 using FPGA (field programmable gate array) technology,  
specifically 4000 series architecture of Xilinx Corporation.  
Other suitable construction techniques include printed circuit  
boards and ASICs (application specific integrated circuits).

The above description is included to illustrate the  
25 operation of the preferred embodiments and is not meant to  
limit the scope of the invention. The scope of the invention  
is to be limited only by the following claims. From the above  
discussion, many variations will be apparent to one skilled in

1 the art that would yet be encompassed by the spirit and scope  
of the invention.

What is claimed is:

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## C L A I M S

1. A computer system comprising:  
at least one central processing unit (CPU) capable of  
5 performing operations on data stored within a set of system  
resources; and  
a scalable coprocessor coupled to the CPUs and to the  
system resources, said scalable coprocessor comprising:  
coupled to the CPUs via a system bus, a single  
10 register file compartmentalized into at least two bins, each  
bin corresponding to a virtual coprocessor channel;  
coupled to the register file and to the system  
resources, a single actual coprocessor for performing  
operations on the system resources; and  
15 coupled to the register file, means for apportioning  
the operational time of the actual coprocessor among the set of  
virtual coprocessor channels.
2. The computer system of claim 1 wherein the system  
20 resources comprise memory and input/output device controllers.
3. The computer system of claim 1 wherein the number  
of bins is variable and is preselected.
- 25 4. The computer system of claim 1 wherein the actual  
coprocessor comprises means for performing any combination of  
any arithmetic, logic, and shift operations on multiple blocks  
of data within the system resources.



1           5. The computer system of claim 1 wherein the  
apportioning means comprises means for determining the order  
and duration for which the virtual coprocessor channels are  
given operational authorization.

5

6. The computer system of claim 5 wherein the  
determining means comprises a programmable throttle which sets  
the number of operations each virtual channel is allowed to  
perform during each operational authorization.

10

7. The computer system of claim 6 wherein idle  
periods are interspersed between throttle (operational)  
periods; and

15 the system bus is free to be used by the CPUs during  
the idle periods.

8. The computer system of claim 1 wherein the actual  
coprocessor is fly-by DMA controller.

20

9. The computer system of claim 1 wherein the actual  
coprocessor is a RAID (redundant array of inexpensive disks)  
coprocessor.

10. The computer system of claim 1 wherein the actual  
25 coprocessor is a striping coprocessor.

11. The computer system of claim 1 wherein the actual  
coprocessor comprises a byte counter coupled to the register

1 file via a pointer bus, at least one address pointer coupled to  
the register file via the pointer bus, and a buffer coupled to  
the address pointer(s), the byte counter, and the pointer bus.

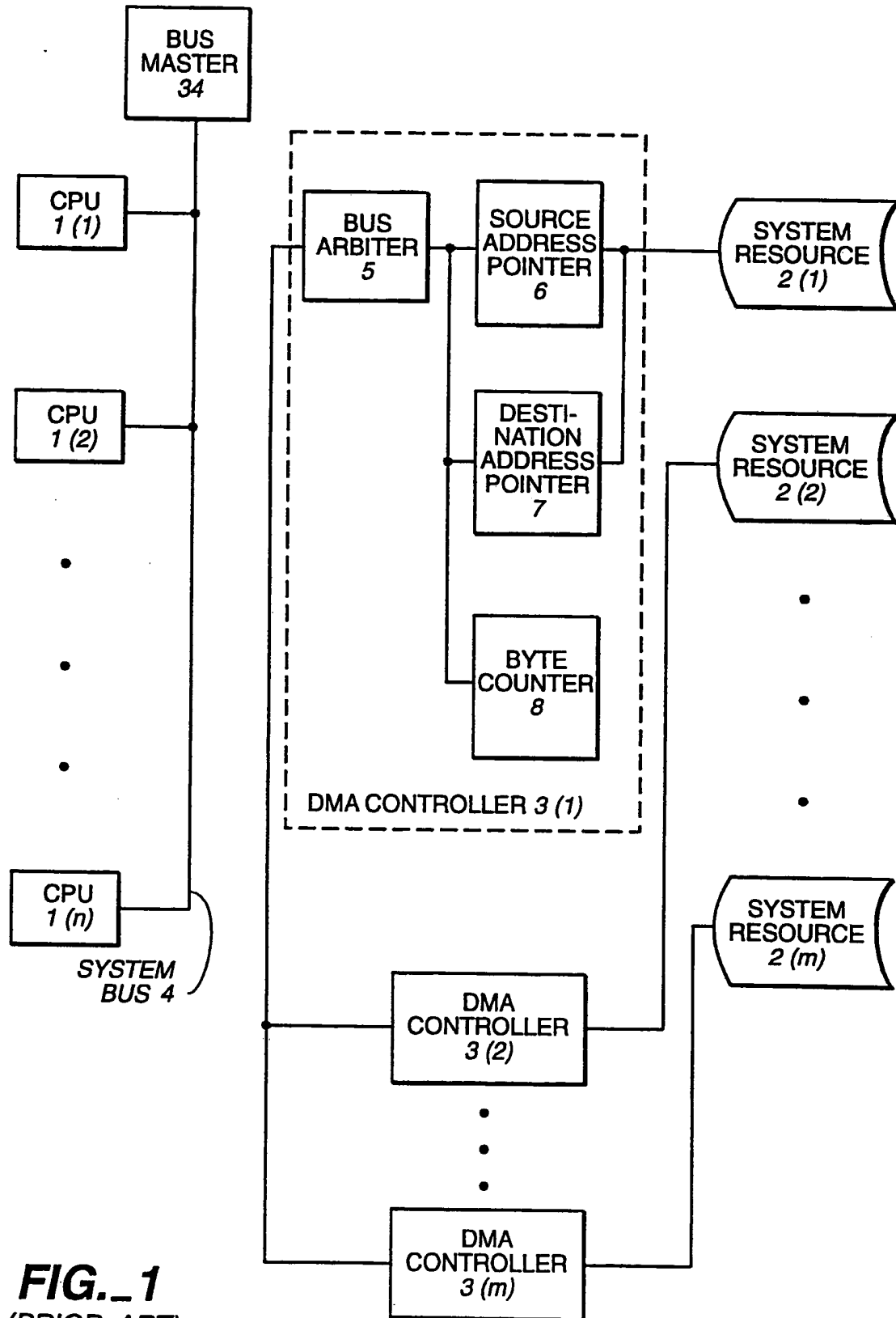
5

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**FIG. 1**  
(PRIOR ART)

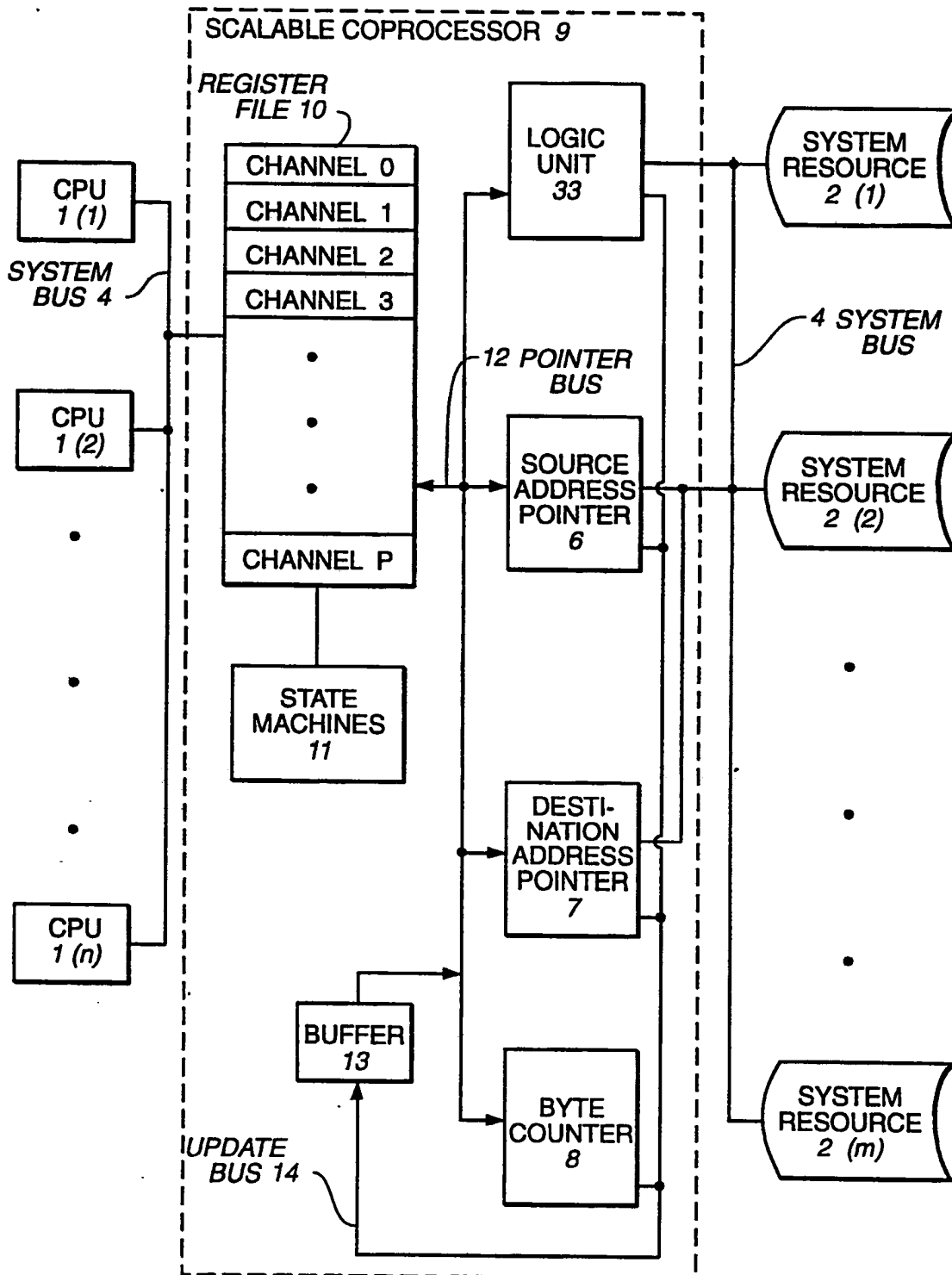


FIG. 2

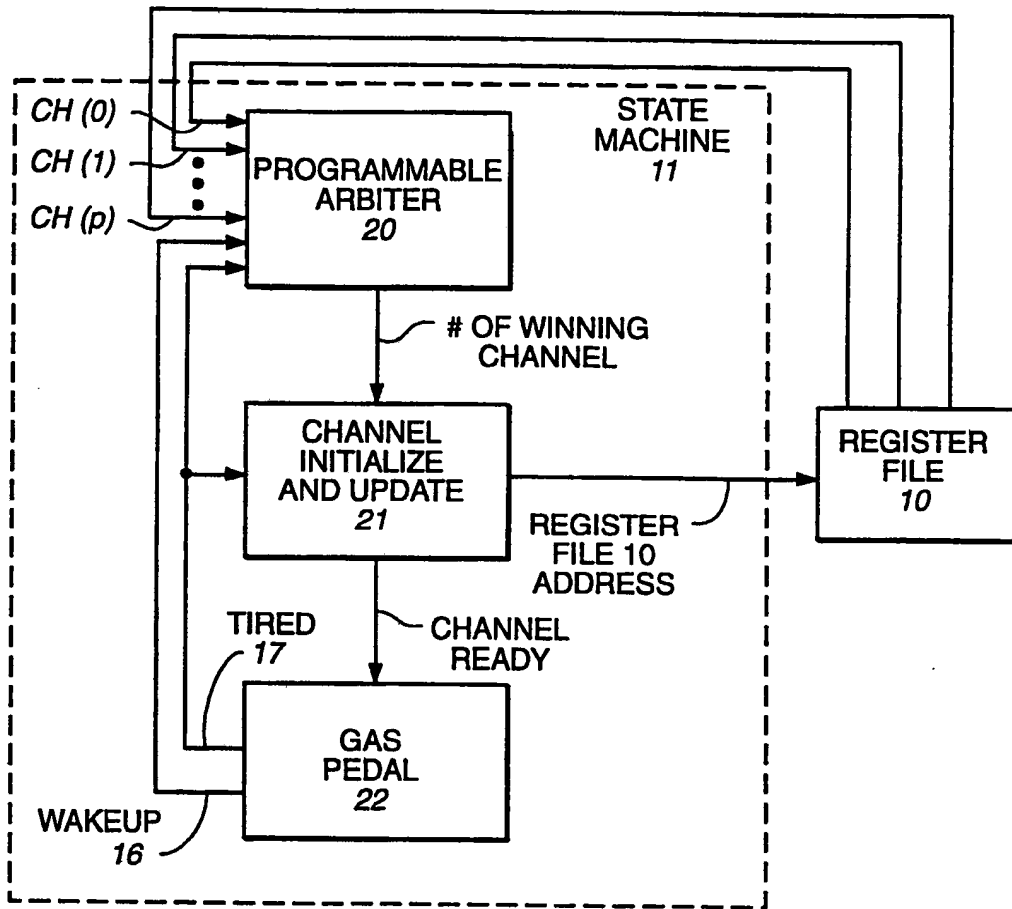


FIG. 3

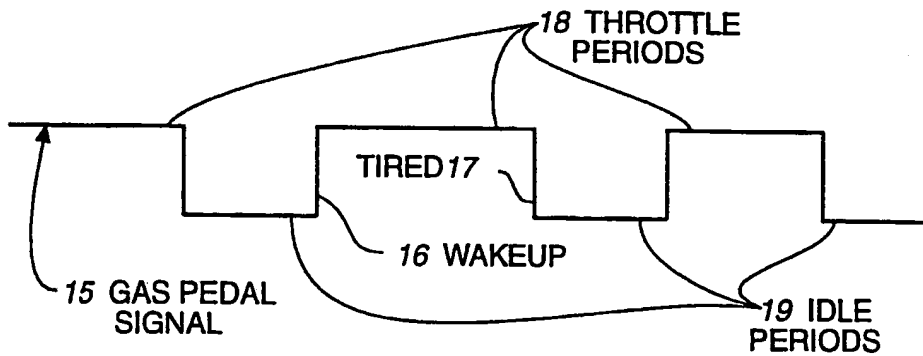
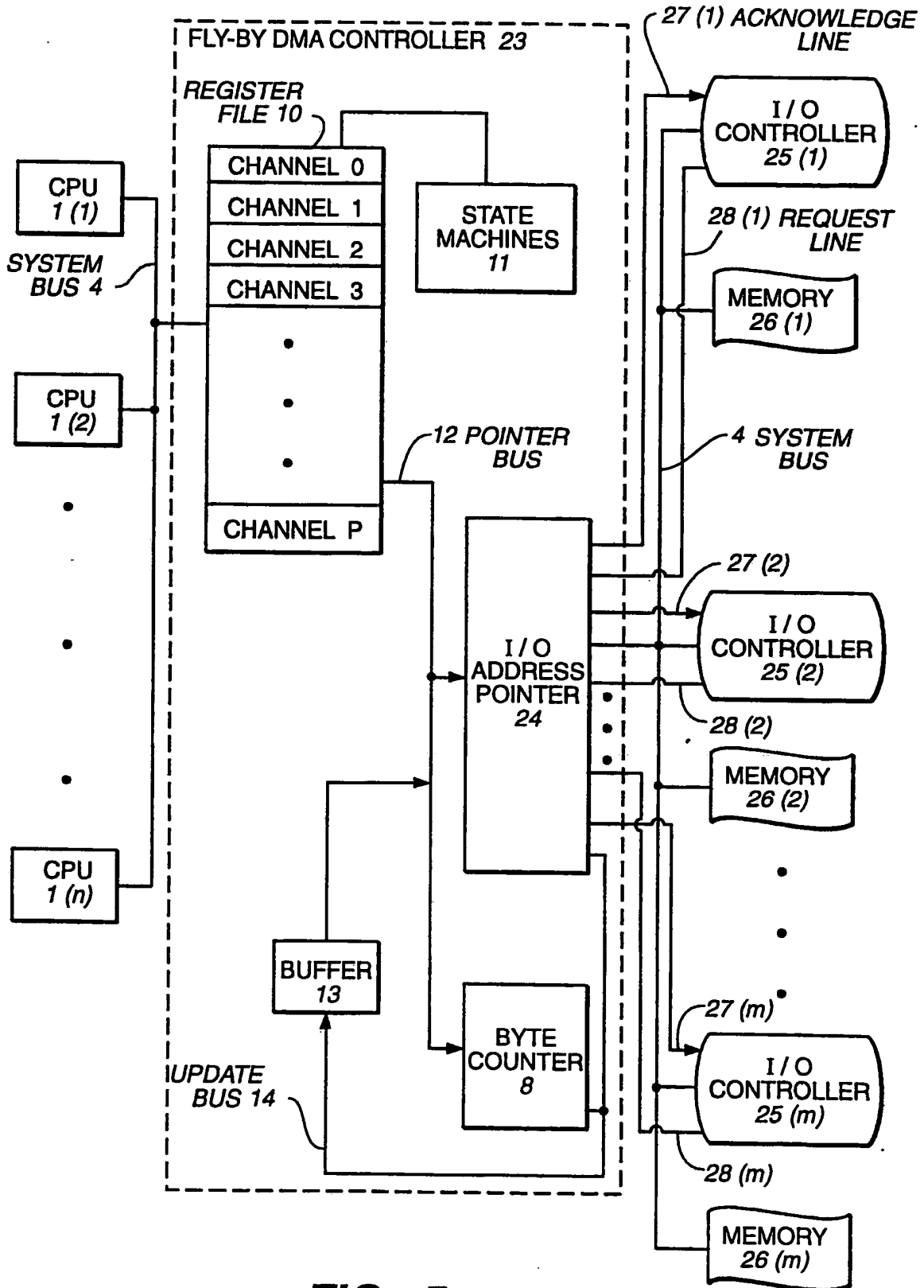


FIG. 4



**FIG. 5**  
4 / 5  
SUBSTITUTE SHEET

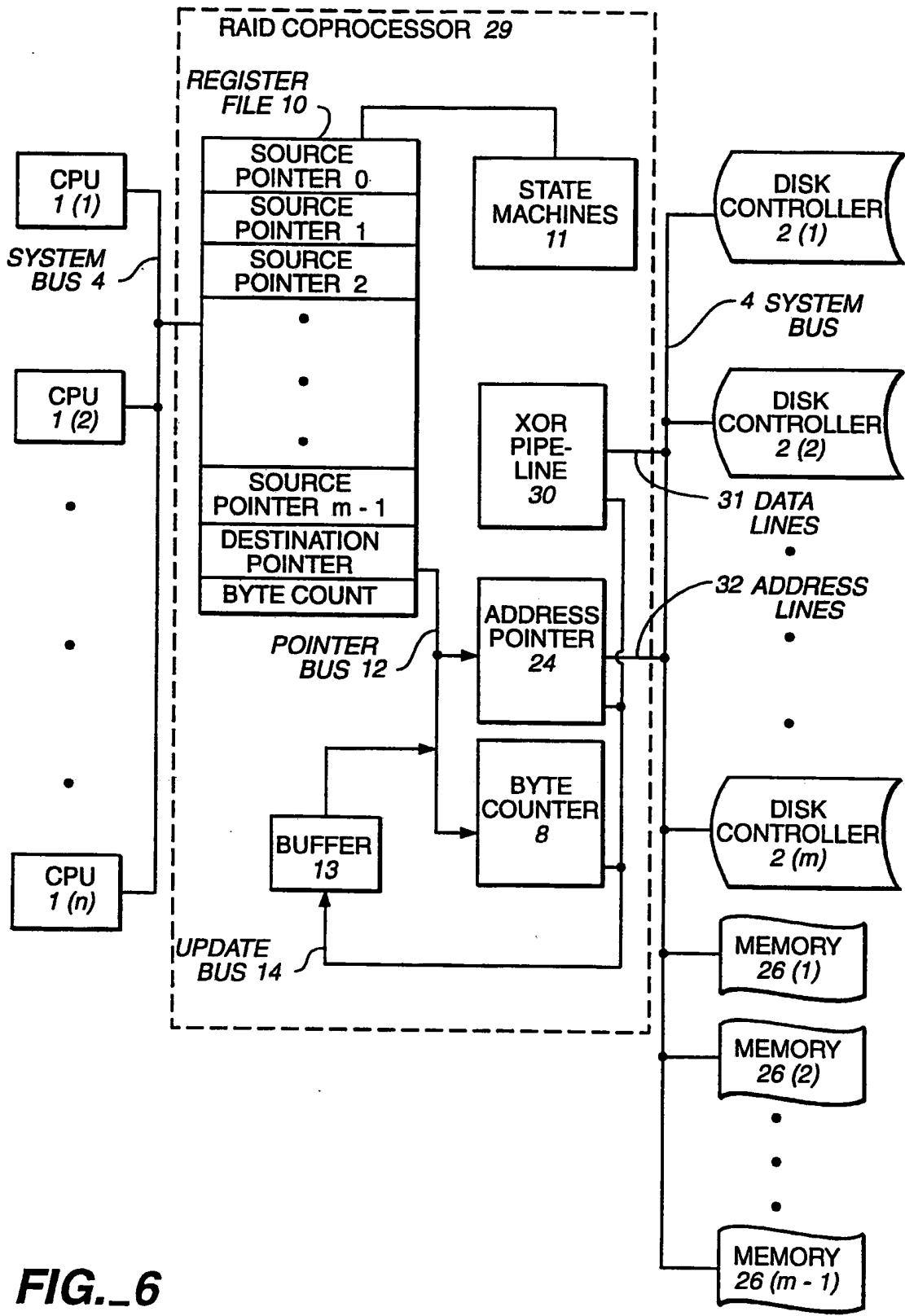


FIG. 6

**INTERNATIONAL SEARCH REPORT**

PCT/JP 93/00617

International Application No

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC		
Int.Cl. 5 G06F13/12;                      G06F13/28;                      G06F3/06		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
Int.Cl. 5	G06F	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>		
Category <sup>10</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
Y	WO,A,9 111 767 (AUSPEX SYSTEMS, INC.) 8 August 1991 see page 52, line 13 - page 66, line 8; figures 1,15,16  ---	1-3,5-8, 11
Y	EP,A,0 365 116 (HEWLETT-PACKARD LIMITED) 25 April 1990 see page 3, line 46 - page 4, line 41; figures 1-3  ---	1-3,5-8, 11
A	GB,A,2 211 325 (ZIITT) 28 June 1989 see page 1, line 5 - page 3, line 7; figure 1  ---	1-3,8,11
	-/--	
<p><sup>10</sup> Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&amp;" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
06 SEPTEMBER 1993	10.09.93	
International Searching Authority	Signature of Authorized Officer	
EUROPEAN PATENT OFFICE	JONES H.D.	



III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category <sup>a</sup>	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	EP,A,0 482 819 (ARRAY TECHNOLOGY CORPORATION) 29 April 1992 see page 3, column 4, line 6 - page 5, column 8, line 6; figures 1,3 -----	1,4,9,10

**ANNEX TO THE INTERNATIONAL SEARCH REPORT  
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